APPLICATION FOR UNITED STATES LETTERS PATENT

for

A PROCESS TO PRODUCE A DILUTE ETHYLENE STREAM AND A DILUTE PROPYLENE STREAM

by

Rodney L. Porter, Anne M. Balinsky and Eric P. Weber

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Kim Gregg 2-27-2002
Kim Gregg

This is a Continuation-In-Part of application serial no 09/992,445, filed on November 16, 2001 from which applicants claim priority under 37 C.F.R.1.78.

FIELD OF THE INVENTION

This invention is related to the field of processes wherein a cracked gas stream is separated to produce dilute olefin streams to be used as feedstocks to produce olefin-based derivatives. Specifically, this invention is related to the field of processes wherein a cracked gas stream is separated to produce a dilute ethylene stream and a dilute propylene stream to be used as feedstocks for producing olefin-based derivatives. More specifically, the dilute ethylene stream is used as a feedstock to produce ethylbenzene, and the dilute propylene stream is used as a feedstock to produce cumene, acrylic acid, propylene oxide or other propylene based derivatives.

BACKGROUND OF THE INVENTION

Feedstock costs in the chemical industry comprise a significant portion of the manufacturing costs. Continuous research is being conducted to lower these costs by utilizing lower cost feed sources. The alkylation of benzene and other aromatics is one area where dilute olefin streams are employed to reduce feed related manufacturing costs. For example, in the production of ethylbenzene, a raw material for the production of styrene, the off-gas from a fluidized catalytic cracking unit (FCC) can be successfully employed as a cost advantaged ethylene source. The FCC off-gas is a dilute stream containing typically less than 30 mole percent ethylene. Due to the large quantities of diluents in the FCC off-gas, such as, for example, hydrogen and methane, the alkylation section of the ethylbenzene unit requires that some of the equipment be oversized. Additionally, the hydrogen sulfide content of the FCC off-gas necessitates its removal in a gas pre-treatment section and subsequent compression before it can be routed to the alkylation reactor. The requirements of having oversized equipment and gas pre-treatment followed by compression greatly

increase the capital costs associated with an ethylbenzene unit utilizing FCC off-gas as its feedstock compared to a conventional ethylbenzene unit that utilizes high purity, polymer grade ethylene.

There is a need in the chemical industry to reduce feedstock costs by utilizing dilute olefin streams at olefins-based derivative units rather than polymer grade olefin feedstocks. To fulfill this need, the inventors provide this inventive process. This process reduces the amount of equipment traditionally required for the production of ethylene. An example of some of the equipment that has been eliminated is the ethylene refrigeration compressor, demethanizer, cold box system, and C_2 and C_3 splitters. Additionally, some equipment is smaller than with conventional crackers of comparable scale. The propylene refrigeration system is reduced in size over that of a conventional cracker. This invention also benefits the olefin-based derivative units that produce, for example, ethylbenzene, cumene, acrylic acid, and propylene oxide. One of the benefits is the pretreatment normally required for the olefins-based derivative units is not necessary in this inventive process because treatment has already been accomplished in the process to produce the dilute olefins stream. In others words, this inventive process to produce dilute olefin streams and route these stream to olefins-based derivative units has a reduced capital cost over a traditional FCC off-gas process since all pretreatment and compression is handled by the dilute olefins process.

SUMMARY OF THE INVENTION

An object of this invention is to provide a process to produce a dilute ethylene stream and a dilute propylene stream from a cracked gas stream.

Another object of this invention is to provide a process to produce the dilute ethylene stream and the dilute propylene stream from a cracked gas stream generated by the steam cracking of C_2 and higher hydrocarbons.

Another object of this invention is to provide a process to produce the dilute ethylene stream and dilute propylene stream wherein these streams are utilized to produce olefin-based derivatives.

Another object of this invention is to provide a process to produce a dilute ethylene stream wherein the dilute ethylene stream is used as a feedstock to produce ethylbenzene.

Another object of this invention is to provide a process to produce a dilute ethylene stream wherein the ethylbenzene unit utilizing the dilute ethylene stream does not contain pretreatment and compression zones.

Another object of this invention is to provide a process to produce a dilute propylene stream wherein the dilute propylene stream is used as a feedstock to produce cumene, acrylic acid, propylene oxide and other propylene derivatives.

Yet another object of this invention is to produce cumene, acrylic acid, and propylene oxide and other propylene derivatives without a pretreatment unit.

In accordance with one embodiment of this invention, a process for producing a dilute ethylene stream and a dilute propylene stream from a cracked gas stream is provided, the process comprising (or optionally, "consisting essentially of" or "consisting of") the following steps in the order named:

(1) separating the cracked gas stream in a deethanizer zone to produce a C_2 – stream and a C_3+ stream;

(2). hydrogenating the C_2- stream in a hydrogenation zone to remove a portion of the acetylene to produce the dilute ethylene stream;

(3) separating the C_3+ stream in a depropanizer zone to produce a C_3 stream and a C_4+ stream; and

(4) reacting the C_3 stream in a methylacetylene-propadiene hydrogenation (MAPD) reactor zone to convert a portion of methylacetylene and propadiene to propylene and propane to produce the dilute propylene stream.

In accordance with another embodiment of this invention, a process for producing the cracked gas stream is provided, the process comprising (or optionally, "consisting essentially of" or "consisting of"):

(1) heating a hydrocarbon feed in a cracking zone to form a raw cracked gas stream; wherein the raw cracked gas stream comprises hydrogen, methane, C_2 hydrocarbons, C_3 hydrocarbons and heavier constituents;

(2) quenching the raw cracked gas stream in a quenching zone to produce a quenched, cracked gas stream;

(3) compressing the quenched, cracked gas stream in a first compression zone to form a pressurized, cracked gas stream;

(4) deacidifying the pressurized, cracked gas stream in a deacidifying zone to remove a portion of the hydrogen sulfide to form a wet cracked gas stream; and

(5) drying the wet cracked gas stream in a drying zone to form a cracked gas stream.

In accordance with another embodiment of this invention, a process for producing a dilute ethylene stream and a dilute propylene stream is provided, the process comprising (or optionally, "consisting essentially of" or "consisting of") the following steps in the order named:

(1) separating the cracked gas stream in a deethanizer zone to produce a C_2 – stream and a C_3+ stream;

(2) compressing the C_2- stream in a compression zone to form a pressurized C_2- stream;

(3) hydrogenating the pressurized C_2- stream in a hydrogenation zone to remove a portion of the acetylene to produce the dilute ethylene stream;

(4) separating the C_3+ stream in a depropanizer zone to produce a C_3 stream and a C_4+ stream; and

(5) reacting the C_3 stream in a MAPD reactor zone to convert a portion of methylacetylene and propadiene to propylene and propane to produce the dilute propylene stream.

In accordance with another embodiment of this invention, a process for producing a dilute ethylene stream and a dilute propylene stream is provided, the process comprising (or optionally, "consisting essentially of" or "consisting of") the following steps in the order named:

(1) hydrogenating a portion of the acetylene in the cracked gas stream in a hydrogenation zone to produce a reduced acetylene cracked gas stream;

(2) separating the reduced acetylene cracked gas stream in a deethanizer zone to produce the dilute ethylene stream and a C_3+ stream;

(3) separating the C_3+ stream in the depropanizer zone to produce a C_3 stream and a C_4+ stream; and

(4) reacting the C_3 stream in a MAPD reactor zone to convert a portion of methylacetylene and propadiene to propylene and propane to produce the dilute propylene stream.

In accordance with another embodiment of this invention, a process for producing a dilute ethylene stream and a dilute propylene stream is provided, the process comprising (or optionally, "consisting essentially of" or "consisting of") the following steps in the order named:

(1) heating a hydrocarbon feed in a cracking zone to form a raw cracked gas stream; wherein the cracked gas stream comprises hydrogen, methane, C_2 hydrocarbons, C_3 hydrocarbons and heavier constituents;

(2) quenching the raw cracked gas stream in a quenching zone to produce a quenched, cracked gas stream;

(3) compressing the quenched, cracked gas stream in a first compression zone to form a pressurized cracked gas stream;

(4) deacidifying the pressurized, cracked gas stream in a deacidifying zone to remove a portion of the hydrogen sulfide to form a wet cracked gas stream;

(5) drying the wet cracked gas stream in a drying zone to form a cracked gas stream;

(6) separating the cracked gas stream in a deethanizer zone to produce a C_2- stream and a C_3+ stream;

(7) compressing the C_2- stream in a second compression zone to form a pressurized C_2- stream;

(8) hydrogenating the pressurized C_2- stream in a hydrogenation zone to remove a portion of the acetylene to produce the dilute ethylene stream; and

(9) separating the C_3+ stream in a depropanizer zone to produce a C_3 stream and a C_4+ stream; and

(10) reacting the C_3 stream in a MAPD reactor zone to convert a portion of methylacetylene and propadiene to propylene and propane to produce the dilute propylene stream.

In accordance with another embodiment of this invention, a process for producing a dilute ethylene stream and a dilute propylene stream is provided, the process comprising (or optionally, "consisting essentially of" or "consisting of") the following steps in the order named:

(1) heating a hydrocarbon feed in a cracking zone to form a raw cracked gas stream; wherein the cracked gas stream comprises hydrogen, methane, C_2 hydrocarbons, C_3 hydrocarbons, and heavier constituents;

(2) quenching the raw cracked gas stream in a quenching zone to produce a quenched, cracked gas stream;

(3) compressing the quenched, cracked gas stream in a first compression zone to form a pressurized, cracked gas stream;

(4) deacidifying the pressurized, cracked gas stream in a deacidifying zone to remove a portion of the hydrogen sulfide to form a wet cracked gas stream;

(5) drying the wet cracked gas stream in a drying zone to form a cracked gas stream;

(6) separating the cracked gas stream in a deethanizer zone to produce a C_2- stream and a C_3+ stream;

(7) hydrogenating the C_2- stream in a hydrogenation zone to remove a portion of the acetylene to produce the dilute ethylene stream; and

(8) separating the C_3+ stream in a depropanizer zone to produce a C_3 and a C_4+ stream;

(9) reacting the C_3 stream in a MAPD reactor zone to convert a portion of methylacetylene and propadiene to propylene and propane to produce the dilute propylene stream.

In accordance with another embodiment of this invention, a process for producing a dilute ethylene stream and a dilute propylene stream is provided, the process comprising (or optionally, "consisting essentially of" or "consisting of") the following steps in the order named:

(1) heating a hydrocarbon feed in a cracking zone to form a raw cracked gas stream; wherein the raw cracked gas stream comprises hydrogen, methane, C_2 hydrocarbons, C_3 hydrocarbons and heavier constituents;

(2) quenching the raw cracked gas stream in a quenching zone to produce a quenched, cracked gas stream;

(3) compressing the quenched, cracked gas stream in a first compression zone to form a pressurized, cracked gas stream;

(4) deacidifying the pressurized, cracked gas stream in a deacidifying zone to remove a portion of the hydrogen sulfide to form a wet cracked gas stream; and

(5) drying the wet cracked gas stream in a drying zone to reduce the moisture level to form a cracked gas stream

(6) hydrogenating a portion of the acetylene in the cracked gas stream in a hydrogenation zone to produce a reduced acetylene cracked gas stream;

(7) separating the reduced acetylene cracked gas stream in a deethanizer zone to produce the dilute ethylene stream and a C_3+ stream;

(8) separating the C_3+ stream in the depropanizer zone to produce a C_3 stream and a C_4+ stream; and

(9) reacting the C_3 stream in a MAPD reactor zone to convert a portion of methylacetylene and propadiene to propylene and propane to produce the dilute propylene stream.

In accordance with another embodiment of this invention, a process for producing a dilute ethylene stream is provided, the process comprising (or optionally, “consisting essentially of” or “consisting of”) the following steps in the order named:

(1) separating the cracked gas stream in a deethanizer zone to produce a C_2 – stream and a C_3+ stream;

(2). hydrogenating the C_2- stream in a hydrogenation zone to remove a portion of the acetylene to produce the dilute ethylene stream;

(3) routing the C_3+ stream to storage or other process unit.

In accordance with another embodiment of this invention, a process for producing a dilute ethylene stream is provided, the process comprising (or optionally, "consisting essentially of" or "consisting of") the following steps in the order named:

(1) separating the cracked gas stream in a deethanizer zone to produce a C_2 – stream and a C_3+ stream;

(2) compressing the C_2- stream in a compression zone to form a pressurized C_2- stream;

(3) hydrogenating the pressurized C_2- stream in a hydrogenation zone to remove a portion of the acetylene to produce the dilute ethylene stream; and

(4) routing the C_3+ stream to storage or other process unit.

In accordance with another embodiment of this invention, a process for producing a dilute ethylene stream is provided, the process comprising (or optionally, "consisting essentially of" or "consisting of") the following steps in the order named:

(1) hydrogenating a portion of the acetylene in the cracked gas stream in a hydrogenation zone to produce a reduced acetylene cracked gas stream;

(2) separating the reduced acetylene cracked gas stream in a deethanizer zone to produce the dilute ethylene stream and a C_3+ stream; and

(3) routing the C_3+ stream to storage or other process unit.

In accordance with another embodiment of this invention, a process for producing a dilute ethylene stream is provided, the process comprising (or optionally, "consisting essentially of" or "consisting of") the following steps in the order named:

(1) heating a hydrocarbon feed in a cracking zone to form a raw cracked gas stream; wherein the cracked gas stream comprises hydrogen, methane, C_2 hydrocarbons, C_3 hydrocarbons and heavier constituents;

(2) quenching the raw cracked gas stream in a quenching zone to produce a quenched, cracked gas stream;

(3) compressing the quenched, cracked gas stream in a first compression zone to form a pressurized cracked gas stream;

(4) deacidifying the pressurized, cracked gas stream in a deacidifying zone to remove a portion of the hydrogen sulfide to form a wet cracked gas stream;

(5) drying the wet cracked gas stream in a drying zone to produce a cracked gas stream;

(6) separating the cracked gas stream in a deethanizer zone to produce a C_2- stream and a C_3+ stream;

(7) compressing the C_2- stream in a second compression zone to form a pressurized C_2- stream;

(8) hydrogenating the pressurized C_2- stream in a hydrogenation zone to remove a portion of the acetylene to produce the dilute ethylene stream; and

(9) routing the C_3+ stream to storage or other process unit.

In accordance with another embodiment of this invention, a process for producing a dilute ethylene stream is provided, the process comprising (or optionally, "consisting essentially of" or "consisting of"):

(1) heating a hydrocarbon feed in a cracking zone to form a cracked gas stream; wherein the cracked gas stream comprises hydrogen, methane, C_2 hydrocarbons, C_3 hydrocarbons, and heavier constituents;

(2) quenching the raw cracked gas stream in a quenching zone to produce a quenched, cracked gas stream;

(3) compressing the quenched, cracked gas stream in a first compression zone to form a pressurized cracked gas stream;

(4) deacidifying the pressurized, cracked gas stream in a deacidifying zone to remove a portion of the hydrogen sulfide to form a wet cracked gas stream;

(5) drying the wet cracked gas stream in a drying zone to produce a cracked gas stream;

(6) separating the cracked gas stream in a deethanizer zone to produce a C_2- stream and a C_3+ stream;

(7) hydrogenating the pressurized, C_2- stream in the hydrogenation zone to remove a portion of the acetylene to produce the dilute ethylene stream; and

(8) routing the C_3+ stream to storage or other process unit.

In accordance with another embodiment of this invention, a process for producing a dilute ethylene stream and a dilute propylene stream is provided, the process comprising (or optionally, "consisting essentially of" or "consisting of") the following steps in the order named:

(1) heating a hydrocarbon feed in a cracking zone to form a raw cracked gas stream; wherein the raw cracked gas stream comprises hydrogen, methane, C_2 hydrocarbons, C_3 hydrocarbons, and heavier constituents;

(2) quenching the raw cracked gas stream in a quenching zone to produce a quenched, cracked gas stream;

(3) compressing the quenched, cracked gas stream in a first compression zone to form a pressurized cracked gas stream;

(4) deacidifying the pressurized, cracked gas stream in a deacidifying zone to remove a portion of the hydrogen sulfide to form a wet cracked gas stream; and

(5) drying the cracked gas stream in a drying zone to produce a cracked gas stream.

(6) hydrogenating a portion of the acetylene in the cracked gas stream in a hydrogenation zone to produce a reduced acetylene cracked gas stream;

(7) separating the reduced acetylene cracked gas stream in a deethanizer zone to produce the dilute ethylene stream and a C_3+ stream;

(8) routing the C_3+ stream to storage or other process unit.

In accordance with another embodiment of this invention, a process for producing a dilute ethylene stream and a dilute propylene stream is provided, the process comprising (or optionally, "consisting essentially of" or "consisting of") the following steps in the order named:

(1) Separating a cracked gas stream in a depropanizer zone to form a C_3- stream and a C_4+ stream

(2) Separating the C_3- stream in a deethanizer zone to form a C_2- stream and a C3 stream.

(3) hydrogenating a portion of the acetylene in the C_2- stream in a hydrogenation zone to produce a dilute ethylene stream; and

(4) reacting the C_3 stream in a MAPD zone to convert a portion of methylacetylene and propadiene to propylene and propane to produce said dilute propylene stream.

These objects, and other objects, will become more apparent to others with ordinary skill in the art after reading this disclosure.

Brief Description of Drawings

FIG 1. A diagram showing an embodiment of the process to produce dilute propylene and dilute ethylene.

FIG 2. A diagram showing the preferred method of producing cracked gas feed.

FIG 3. A diagram showing another embodiment of the process to produce dilute propylene and dilute ethylene with a second compression zone.

FIG 4. A diagram showing another embodiment of the process to produce dilute ethylene and dilute propylene with a hydrogenation zone before the deethanizer zone.

FIG 5. A diagram for a process to produce dilute ethylene.

FIG 6. A diagram for a process to produce dilute ethylene with a second compression zone.

FIG 7. A diagram for a process to produce dilute ethylene with a hydrogenation zone before the deethanizer zone.

FIG 8. A diagram for a process to produce dilute ethylene and dilute propylene with a depropanizer zone as the first separation.

DETAILED DESCRIPTION OF THE INVENTION

In a first embodiment of this invention, a process for producing a dilute ethylene stream and a dilute propylene stream from a cracked gas stream is provided as shown in Figure 1.

Step (1) is separating the cracked gas stream in line **10** in a deethanizer zone **15** to produce a C_2- stream in line **20** and a C_3+ stream in line **45**. The deethanizer zone **15** comprises a fractionator sufficient to produce the C_2- stream in line **20** and a C_3+ stream in line **45**. The C_2- stream comprises hydrogen, methane, ethane, acetylene and ethylene. The C_3+ stream comprises C_3 hydrocarbons and heavier constituents. The cracked gas stream in line **10** comprises hydrogen, methane, C_2 hydrocarbons, C_3 hydrocarbons, and heavier constituents, and can be produced by any means known in the art.

Step (2) is hydrogenating the C_2- stream in line **20** in a hydrogenation zone **25** to remove a portion of the acetylene to produce the dilute ethylene stream in line **30**. Hydrogenation in the hydrogenating zone **25** can be completed by any means known in the art. For example, an acetylene reactor containing catalyst can be utilized to hydrogenate a portion of the acetylene. Typically, Group VIII metal hydrogenation catalysts are utilized. Hydrogenation catalysts are disclosed in

U.S. Patent Numbers 3,679,762; 4,571,442; 4,347,392; 4,128,595; 5,059,732; 5,488,024; 5,489,565; 5,520,550; 5,583,274; 5,698,752; 5,585,318; 5,587,348; 6,127,310 and 4,762, 956; all of which are herein incorporated by reference. Generally, the amount of acetylene remaining in the dilute ethylene stream in line **30** is in a range of less than about 5 ppm by weight, preferably, in a range of 0.5 ppm to 3 ppm by weight.

The temperature and pressure in the hydrogenation zone **25** is that which is sufficient to substantially hydrogenate the acetylene in the C_2- stream in line **20**. Preferably, the hydrogenating occurs at a temperature in a range of about 50°F to about 400°F and at a pressure in a range of about 350 psia to about 600 psia.

Generally, the amount of ethylene in the dilute ethylene stream in line **30** is in a range of about 30% to about 60% by weight, preferably, 40% to 60 % by weight. The dilute ethylene stream in line **30** then can be routed to a dilute ethylene derivative unit **35** to produce different chemicals in line **40** including, but not limited to, ethylbenzene. Preferably, the dilute ethylene stream in line **30** is routed to an ethylbenzene unit. The ethylbenzene unit can utilize any process known in the art. For example, a Friedel-Crafts alkylation reaction of benzene by ethylene is used. Optionally, an effluent gas stream in line **41** from the dilute ethylene derivative unit **35** can be recycled to a cracking zone **105,** shown in Figure 2, to produce more dilute ethylene. The composition of the effluent gas stream can vary widely depending on the predominant hydrocarbon feed initially fed to the cracking zone **105**. Typically, the effluent gas stream comprises hydrogen, methane, and other light hydrocarbons. Hydrogen and methane may need to be removed from the dilute process stream prior to recycle. This removal can be accomplished by separation membranes, separators, or other equipment.

Step (3) is separating the C_3+ stream in line **45** in a depropanizer zone **50** to produce a C_3 stream in line **55** and a C_4+ stream in line **80**. The depropanizer zone **50** comprises a fractionator

sufficient to produce the C_3 stream in line **55** and a C_4+ stream in line **80**. The C_3 stream in line **55** comprises propane, propylene, methylacetylene and propadiene. The amount of propylene in the C_3 stream in line **55** is in a range of about 55% to about 98% by weight, preferably, in a range of 85% to 96% by weight. The C_4+ stream in line **80** comprises C_4 hydrocarbons and heavier hydrocarbon constituents.

Step (4) is reacting the C_3 stream in line **55** in a MAPD reactor zone **60** to remove a portion of methylacetylene and propadiene to produce the dilute propylene stream in line **62**. The hydrogenation process for the reduction of MAPD occurs in the MAPD reactor zone **60** can be completed by any means known in the art. Generally, the amount of methylacetylene and propadiene remaining in the dilute propylene stream in line **62** is less than 2 ppm by weight.

The dilute propylene stream in line **62** can be routed to an dilute propylene derivative unit **70** to produce different dilute propylene derivatives. For example, the dilute propylene stream in line **62** can be routed to a process to produce cumene, propylene oxide or acrylic acid in line **75**. Cumene can be produced by any process known in the art. For example, a Friedel-Crafts alkylation reaction of benzene by propylene is used to produce cumene. Cumene then can be used to produce other products, such as, for example, phenols.

Optionally, the C_4+ stream in line **80** is separated in a debutanizer zone **85** to produce a C_4 stream in line **90** and a C_5+ stream in line **95**. The debutanizer zone **85** comprises a fractionator sufficient to produce the C_4 stream in line **90** and a C_5+ stream in line **95**. The C_4 stream in line **90** comprises C_4 hydrocarbons. The C_5+ stream in line **95** comprises C_5 hydrocarbons and heavier hydrocarbon constituents.

Optionally, the C_5+ stream in line **95** is treated in a hydrotreating zone **98** to produce a C_5 diolefins stream in line **96,** a benzene-toluene-xylenes (BTX) stream in line **99,** a dicyclopentadiene (DCPD) stream in line **97** and a fuel oil stream in line **94**. The treatment of the C_5+ stream in the

hydrotreating zone **98** can be accomplished by any means known in the art. For example, U.S patent number 6,258,989 discloses a hydrotreating zone that can be utilized in this invention, herein incorporated by reference. The C_5 diolefins stream in line **96** comprises C_5 hydrocarbons, and the BTX stream in line **99** comprises benzene, toluene, and xylenes. The DCPD stream in line **97** comprises dicyclopentadiene, and the fuel oil stream in line **94** comprises C_8+ hydrocarbons.

In a second embodiment of the invention, the cracked gas stream utilized as the feedstock in this process can be produced by any process known in the art. A preferred process for producing the cracked gas stream is provided as shown in Figure 2.

Step (1) is heating a hydrocarbon feed in line **100** in a cracking zone **105** to produce a raw cracked gas stream in line **110**. Generally, the hydrocarbon feed in line **100** comprises at least one hydrocarbon selected from the group consisting of ethane, propane, butane, pentane, naphtha, gas condensates, gas oils, and mixtures thereof. Preferably, a majority of the hydrocarbon feed in line **100** consists of C_5 hydrocarbons and higher hydrocarbons.

The cracking zone **105** comprises at least one radiant furnace reactor capable of producing the raw cracked gas stream in line **110**. Typically, dilution stream is added to the radiant furnace reactors to reduce coking and to reduce the partial pressure of the hydrocarbon feed, thus increasing ethylene yield. Radiant furnace reactors are disclosed in U.S. Patent Numbers 5,151,158; 4,780,196; 4,499,055; 3,274,978; 3,407,789; and 3,820,955; all of which are herein incorporated by reference.

The raw cracked gas stream in line **110** comprises hydrogen, methane, C_2 hydrocarbons, C_3 hydrocarbons, and heavier constituents. Generally, the raw cracked gas stream in line **110** comprises at least about 10% by weight ethylene, preferably, at least about 20% by weight ethylene, and most preferably, at least about 30% by weight ethylene. For example, the raw cracked gas stream in line **110** comprises about 1 to about 5 weight percent hydrogen, about 3 to about 25 weight percent methane, less than about 1 weight percent acetylene, about 25 to about 35 weight

percent ethylene, about 3 to about 45 weight percent ethane, and up to about 55 weight percent C_3+ hydrocarbons, depending on the hydrocarbon feed.

Step (2) is quenching the raw cracked gas stream in line **110** in a quenching zone **115** to produce a quenched, cracked gas stream in line **120**. Typically, the raw cracked gas stream in line **110** is quenched in quenching zone **115** to a temperature below which the cracking reaction substantially stops in order to prevent coking. Generally, the raw cracked gas stream in line **110** is cooled to a temperature below about 1100°F to substantially stop the cracking reaction. Preferably, the raw cracked gas stream in line **110** is cooled to a temperature in a range of about 85 to about 225 °F to form the quenched cracked gas stream in line **120**. Quenching can be effected by any means known in the art. For example, the raw cracked gas stream in line **110** can be passed to a quench boiler and quench tower where fuel oil and dilution stream can be removed. Method for cooling a raw cracked gas stream are disclosed in U.S. Patents 3,407,798; 5,427,655; 3,392,211; 4,3351,275; and 3,403,722, all herein incorporated by reference.

Step (3) is compressing the quenched, cracked gas stream in line **120** in a first compression zone **125** to produce a pressurized, cracked gas stream in line **130**. The pressure of the pressurized, cracked gas stream in line **130** is in a range of about 150 psig to about 650 psig. The first compression zone **125** comprises at least one gas compressor. Any gas compressor known in the art can be utilized.

Step (4) is deacidifying the pressurized, cracked gas stream in line **130** in a deacidifying zone **135** to remove a portion of the hydrogen sulfide and carbon dioxide to form a wet cracked gas stream in line **140**. Generally, the wet cracked gas stream in line **140** has a hydrogen sulfide concentration less than about 0.1 ppm by weight, preferably, in a range of 25 to 100 ppb by weight. Generally, the wet cracked gas stream has a carbon dioxide concentration of less than about 5 ppm

by weight. The hydrogen sulfide can be removed in the deacidifying zone **135** by any means known in the art. For example, diethanolamine or caustic contactors can be used to remove hydrogen sulfide and carbon dioxide.

Step (5) is drying the wet cracked gas stream in line **140** in a drying zone **145** to produce the cracked gas stream in line **150**. Generally, the water content of the cracked gas stream in line **150** is sufficiently dry to prevent downstream operational problems. Preferably, the water content of the cracked gas stream in line **150** is less than 10 ppm by weight. Drying in drying zone **145** can be accomplished by any means known in the art. For example, molecular sieve beds can be utilized to remove water from the wet cracked gas stream in line **140**.

In a third embodiment of this invention, a process for producing a dilute ethylene stream and dilute propylene stream from a cracked gas stream is provided as shown in Figure 3.

Step (1) is separating the cracked gas stream in line **155** in a deethanizer zone **160** to produce a C_2- stream in line **165** and a C_3+ stream in line **200**. The deethanizer zone **160** comprises a fractionator sufficient to produce the C_2- stream in line **165** and a C_3+ stream in line **200**. The C_2- stream comprises hydrogen, methane, ethane, acetylene and ethylene. The C_3+ stream comprises C_3 hydrocarbons and heavier constituents.

Step (2) is compressing the C_2- stream in line **165** in a second compression zone **170** to produce a pressurized, C_2- stream in line **175**. The pressure of the pressurized, C_2- stream in line **175** is in a range of about 150 to about 650 psig, preferably, in a range of 200 to 650 psig. The second compression zone **170** comprises a gas compressor and related equipment. Any gas compressor known in the art can be utilized.

Step (3) is hydrogenating the pressurized C_2- stream in line **175** in a hydrogenation zone **180** to remove a portion of the acetylene to produce the dilute ethylene stream in line **185.** The hydrogenation zone **180** is the same as previously described in the first embodiment.

Generally, the amount of ethylene in the dilute ethylene stream in line **185** is in a range of about 30% to about 60% by weight, preferably, 40% to 60 % by weight. The dilute ethylene stream in line **185** then can be routed to an dilute ethylene derivative unit **190** to produce different chemicals in line **195** including, but not limited to, ethylbenzene. The dilute ethylene derivative unit **190** is the same as dilute ethylene derivative unit **35** previously described in the first embodiment. Optionally, an effluent gas stream in line **191** from the dilute ethylene derivative unit **190** can be recycled to a cracking zone **105** in Figure 2.

Step (4) is separating the C_3+ stream in line **200** in a depropanizer zone **205** to produce a C_3 stream in line **210** and a C_4+ stream in line **235**. The depropanizer zone **205** and the C_3 stream and the C_4+ stream are the same as previously described in the first embodiment.

Step (5) is reacting the C_3 stream in line **210** in a MAPD reactor zone **215** to remove a portion of methylacetylene and propadiene to produce the dilute propylene stream in line **217**. The MAPD reactor zone **215** is the same as MAPD reactor zone **60** previously described in the first embodiment. The dilute propylene stream is the same as previously described in the first embodiment.

The dilute propylene stream in line **217** then can be routed to a dilute propylene derivative unit **225** to produce different dilute propylene derivatives in line **230**. The dilute propylene derivative unit **225** is the same as dilute propylene derivative unit **70** previously described in the first embodiment.

Optionally, the C_4+ stream in line **235** is separated in a debutanizer zone **240** to produce a C_4 stream in line **245** and a C_5+ stream in line **250**. The debutanizer zone **240** comprises a fractionator sufficient to produce the C_4 stream in line **245** and a C_5+ stream in line **250**. The debutanizer zone **240** and the C_4 stream in line **245** and the C_5+ stream in line **250** are the same as previously described in the first embodiment.

Optionally, the C_5+ stream in line **250** is treated in a hydrotreating zone **255** to produce a C_5 diolefins stream in line **256,** a BTX stream in line **257,** a DCPD stream in line **258,** and a fuel oil stream in line **254**. The hydrotreating zone **255,** the C_5 diolefins stream in line **256,** the BTX stream in line **257,** and the DCPD stream in line **258** and the fuel oil stream in line **254** are the same as previously described in the first embodiment.

In a fourth embodiment of this invention, a process for producing a dilute ethylene and dilute propylene stream from a cracked gas stream is provided as shown in Figure 4.

Step (1) is hydrogenating the cracked gas stream in line **260** in a hydrogenation zone **265** to remove a portion of the acetylene to produce a reduced acetylene cracked gas stream in line **270.** The hydrogenation zone **265** is the same as previously described in the first embodiment.

Step (2) is separating the reduced acetylene cracked gas stream in line **270** in a deethanizer zone **275** to produce the dilute ethylene stream in line **280** and a C_3+ stream in line **295**. The deethanizer zone **275** comprises a fractionator sufficient to produce the dilute ethylene stream in line **280** and a C_3+ stream in line **295**. The deethanizer zone **275**, dilute ethylene stream in line **280** and C_3+ stream in line **295** are the same as previously described in the first and third embodiments.

Generally, the amount of ethylene in the dilute ethylene stream in line **280** is in a range of about 30% to about 60% by weight, preferably, 40% to 60 % by weight. The dilute ethylene stream in line **280** then can be routed to an dilute ethylene derivative unit **285** to produce different chemicals in line **290** including, but not limited to, ethylbenzene. The dilute ethylene derivative unit **285** is the same as dilute ethylene derivative unit **35** previously described in the first embodiment. Optionally, an effluent gas stream in line **286** from the dilute ethylene derivative unit **285** can be recycled to a cracking zone **105** in Figure 2.

Step (3) is separating the C_3+ stream in line **295** in a depropanizer zone **300** to produce a C_3 stream in line **305** and a C_4+ stream in line **330**. The depropanizer zone **300,** the C_3 stream in line **305,** and the C_4+ stream in line **330** are the same as previously described in the first embodiment.

Step (4) is reacting the C_3 stream in line **305** in a MAPD reactor zone **310** to remove a portion of methylacetylene and propadiene to produce the dilute propylene stream in line **312**. The MAPD reactor zone **310** and the dilute propylene stream in line **312** is the same as previously described in the first embodiment.

The dilute propylene stream in line **312** can be routed to a dilute propylene derivative unit **320** to produce different dilute propylene derivatives line **325**. The dilute propylene derivative unit **320** is the same as previously described in the first and third embodiments.

Optionally, the C_4+ stream in line **330** is separated in a debutanizer zone **335** to produce a C_4 stream in line **340** and a C_5+ stream in line **345**. The debutanizer zone **335** comprises a fractionator sufficient to produce the C_4 stream in line **340** and a C_5+ stream in line **345**. The debutanizer zone **335**, the C_4 stream in line **340,** and the C_5+ stream in line **345** are the same as previously described in the first and third embodiments.

Optionally, the C_5+ stream in line **345** is treated in a hydrotreating zone **350** to produce a C_5 diolefins stream in line **351,** a BTX stream in line **352,** a DCPD stream in line **353,** and a fuel oil stream in line **354**. The hydrotreating zone **350**, the C_5 diolefins stream in line **351,** the BTX stream in line **352,** the DCPD stream in line **353,** and the fuel oil stream in line **354** are the same as previously described in the first embodiment.

In a fifth embodiment of this invention, a process for producing a dilute ethylene stream from a cracked gas stream is provided as shown in Figure 5.

Step (1) is separating the cracked gas stream in line **300** in a deethanizer zone **305** to produce a C_2- stream in line **315** and a C_3+ stream in line **310**. The deethanizer zone **305** comprises

a fractionator sufficient to produce the C_2- stream in line **315** and a C_3+ stream in line **310**. The C_2- stream comprises hydrogen, methane, ethane, acetylene and ethylene. The C_3+ stream comprises C_3 hydrocarbons and heavier constituents.

Step (2) is hydrogenating the C_2- stream in line **315** in a hydrogenation zone **320** to remove a portion of the acetylene to produce the dilute ethylene stream in line **325.** The hydrogenation zone **320** and the dilute ethylene stream in line **325** are the same as previously described in the first embodiment.

Generally, the amount of ethylene in the dilute ethylene stream in line **325** is in a range of about 30% to about 60% by weight, preferably, 40% to 60 % by weight. The dilute ethylene stream in line **325** then can be routed to an dilute ethylene derivative unit **330** to produce different chemicals in line **335** including, but not limited to, ethylbenzene. The dilute ethylene derivative unit **330** is the same as dilute ethylene derivative unit **35** previously described in the first embodiment. Optionally, an effluent gas stream in line **331** from the dilute ethylene derivative unit **330** can be recycled to a cracking zone **105** in Figure 2.

Step (3) is routing the C_3+ stream in line **310** to storage or to other process units.

In a sixth embodiment of this invention, a process for producing a dilute ethylene stream from a cracked gas stream is provided as shown in Figure 6.

Step (1) is separating the cracked gas stream in line **400** in a deethanizer zone **405** to produce a C_2- stream in line **415** and a C_3+ stream in line **410**. The deethanizer zone **405** comprises a fractionator sufficient to produce the C_2- stream in line **415** and a C_3+ stream in line **410**. The C_2- stream comprises hydrogen, methane, ethane, acetylene and ethylene. The C_3+ stream comprises C_3 hydrocarbons and heavier constituents.

Step (2) is compressing the C_2- stream in line **415** in a second compression zone **420** to produce a pressurized, C_2- stream in line **425**. The pressure of the pressurized, C_2- stream in line

425 is in a range of about 150 to about 650 psig , preferably, in a range of 200 to 650 psig. The second compression zone **420** comprises a gas compressor and related equipment. Any gas compressor known in the art can be utilized.

Step (3) is hydrogenating the pressurized C_2- stream in line **425** in a hydrogenation zone **430** to remove a portion of the acetylene to produce the dilute ethylene stream in line **435.** The hydrogenation zone **430** is the same as previously described in the first embodiment.

Generally, the amount of ethylene in the dilute ethylene stream in line **435** is in a range of about 30% to about 60% by weight, preferably, 40% to 60 % by weight. The dilute ethylene stream in line **435** then can be routed to an dilute ethylene derivative unit **440** to produce different chemicals in line **445** including, but not limited to, ethylbenzene. The dilute ethylene derivative unit **440** is the same as dilute ethylene derivative unit **35** previously described in the first embodiment. Optionally, an effluent gas stream in line **441** from the dilute ethylene derivative unit **440** can be recycled to a cracking zone **105** in Figure 2.

Step (4) is routing the C_3+ stream in line **410** to storage or to other process units.

In a seventh embodiment of this invention, a process for producing a dilute ethylene stream from a cracked gas stream is provided as shown in Figure 7.

Step (1) is hydrogenating the cracked gas stream in line **500** in a hydrogenation zone **505** to remove a portion of the acetylene to produce a reduced acetylene cracked gas stream in line **510.** The hydrogenation zone **505** is the same as previously described in the first and third embodiment.

Step (2) is separating the reduced acetylene cracked gas stream in line **510** in a deethanizer zone **515** to produce the dilute ethylene stream in line **525** and a C_3+ stream in line **520**. The deethanizer zone **515** comprises a fractionator sufficient to produce the dilute ethylene stream in line **525** and a C_3+ stream in line **520**. The deethanizer zone **515**, dilute ethylene stream in line **525** and C3+ stream in line **520** are the same as previously described in the first embodiment.

Generally, the amount of ethylene in the dilute ethylene stream in line **525** is in a range of about 30% to about 60% by weight, preferably, 40% to 60 % by weight. The dilute ethylene stream in line **525** then can be routed to an dilute ethylene derivative unit **530** to produce different chemicals in line **535** including, but not limited to, ethylbenzene. Optionally, an effluent gas stream in line **531** can be recycled back to a cracking zone **105** shown in Figure 2 to produce more dilute ethylene. The dilute ethylene derivative unit **530** is the same as dilute ethylene derivative unit **35** previously described in the first embodiment.

Step (3) is routing the C_3+ stream in line **520** to storage or to other process units.

In an eighth embodiment of this invention, a process for producing a dilute ethylene stream and dilute propylene stream is provided as in Figure 8.

Step (1) is separating the cracked gas stream in line **800** in a depropanizer zone **805** to produce a C_3- stream in line **810** and a C4+ stream in line **845**. The depropanizer zone **805** comprises a fractionator sufficient to produce the C_3- stream in line **810** and the C_4+ stream in line **845**. The C_3- stream in line **810** comprises hydrogen, methane, ethane, ethylene, acetylene, propane, propylene, methylacetylene and propadiene. The amount of propylene in the C_3 - stream in line **810** is in a range of about 1% to about 32% by weight, preferably, in a range of 15% to 30% by weight. The C_4+ stream in line **845** comprises C_4 hydrocarbons and heavier constituents.

Step (2) is separating the C_3- stream in line **810** in a deethanizer zone **815** to produce a C_2- stream in line **820** and a C_3 stream in line **890**. The deethanizer zone **815** comprises a fractionator sufficient to produce the C_2- stream in line **820** and a C_3 stream in line **890**. The C_2- stream comprises hydrogen, methane, ethane, acetylene, and ethylene. The C_3 stream comprises C_3 hydrocarbons.

Step (3) is hydrogenating the C_2- stream in line **820** in a hydrogenation zone **825** to remove a portion of the acetylene to produce the dilute ethylene stream in line **830**. The hydrogenating zone **825** is the same as previously described in the first embodiment.

Generally, the amount of ethylene in the dilute ethylene stream in line **830** is in a range of about 30% to about 60% by weight, preferably, 40% to 60 % by weight. The dilute ethylene stream in line **830** then can be routed to an dilute ethylene derivative unit **835** to produce different chemicals in line **840** including, but not limited to, ethylbenzene. The dilute ethylene derivative unit **835** is the same as dilute ethylene derivative unit **35** previously described in the first embodiment. Optionally, an effluent gas stream in line **836** from the dilute ethylene derivative unit **835** can be recycled to a cracking zone **105** as shown in Figure 2 for the production of more dilute ethylene.

Step (4) is reacting the C_3 stream in line **890** in a MAPD reactor zone **895** to remove a portion of methylacetylene and propadiene to produce the dilute propylene stream in line **900**. The MAPD reactor zone **895** and the dilute propylene in line **900** are previously described in the first embodiment.

The dilute propylene stream in line **900** then can be routed to a dilute propylene derivative unit **905** to produce different dilute propylene derivatives in line **910**. The dilute propylene derivative unit **905** is the same as dilute propylene derivative unit **70** previously described in the first embodiment.

Optionally, the C_4+ stream in line **845** is separated in a debutanizer zone **850** to produce a C_4 stream in line **855** and a C_5+ stream in line **860**. The debutanizer zone **850** comprises a fractionator sufficient to produce the C_4 stream in line **855** and a C_5+ stream in line **860**. The debutanizer zone **850** and the C_4 stream in line **855,** and the C_5+ stream in line **860** are the same as previously described in the first embodiment.

Optionally, the C_5+ stream in line **860** is treated in a hydrotreating zone **865** to produce a C_5 diolefins stream in line **870,** a BTX stream in line **875,** a DCPD stream in line **880,** and a fuel oil stream in line **885**. The hydrotreating zone **865,** the C_5 diolefins stream in line **870,** the BTX stream in line **875,** the DCPD stream in line **880** and the fuel oil stream in line **885** are the same as previously described in the first embodiment.

In another aspect of this invention, the second embodiment, which provides a preferred process of producing the cracked gas stream, can be combined with either the first, third, fourth, and eight embodiments to yield one continuous process for producing the dilute ethylene stream and dilute propylene stream. Also a second embodiment, can be combined with either the fifth sixth or seventh embodiment to yield one continuous process for producing the dilute ethylene stream.

In another aspect of this invention, the dilute ethylene stream in the eight embodiment previously described is routed to an ethylbenzene process. Processes to produce ethylbenzene are disclosed in U.S patent numbers 5,602,290; 5,880,320; 5,856,607; 6,252,126; all of which are herein incorporated by reference.

An example of utilizing the dilute ethylene stream to produce ethylbenzene is shown in Figure 12.

Step (1) comprises reacting a dilute ethylene stream in line **1300** with a benzene stream in line **1305** in an alkylation reactor zone **1310** to form an ethylbenzene rich stream, line **1315**. The ethylbenzene rich stream in line 1315 comprises benzene and ethylbenzene. The reacting can be accomplished by any means known in the art. For example, the selectivity of converting ethylene to ethylbenzene is greater than 99%. The catalysts used are zeolite catalysts such as a ZSM based zeolite system.

Step (2) comprises separating the ethylbenzene rich stream in line **1315** in a ethylbenzene separation zone **1320** to form a separations tailgas stream in line **1325,** an ethylbenzene stream in

line **1330**, a diethylbenzene and polyethylenebenzene stream in line **1335**, and a separation benzene recycle stream in line **1340**. Separating can be accomplished by any means know in the art. Generally the separating in the ethylbenzene separation zone comprises at least one fractionator.

Step (3) comprises reacting a portion of the separation benzene recycle stream in line **1340** in a transalkylating reactor zone **1345** to produce an ethylbenzene rich stream in line **1315** The reacting can be accomplished by any means known in the art. For example, the selectivity of converting ethylene to ethylbenzene is greater than 99%. The catalysts use are zeolite based catalysts such as the Washington Group' TRA-1 or Lummus' Y-zeolite based catalyst system.

Step (4) is recycling a portion of the separation benzene recycle stream in line **1340** to be combined with the benzene stream in line **1305**.

In another aspect of this invention, the dilute propylene stream produced in the embodiments described is routed to a propylene oxide process. Processes to produce propylene oxide product are disclosed in U.S. Patent 3,849,451, herein incorporated by reference. An example of this process comprises the following steps is shown in Figure 9.

Step (1) comprises reacting a dilute ethylene stream in line **1000** and a benzene stream in line **1005** in an ethylbenzene reactor zone **1010** to form an ethylbenzene stream in line **1015**. The ethylbenzene reactor zone **1010** comprises process equipment sufficient to produce the ethylbenzene stream in line **1015**. Typically, the ethylbenzene zone **1010** comprises an alkylation reactor, a transalkylation reactor, and a separation zone to produce ethylbenzene and other products.

Step (2) comprises oxidizing the ethylbenzene stream in line **1015** with air in line **1021** in an EB oxidation zone **1020** to form an ethylbenzene hydroperoxide (EBHP) stream in line **1025** comprising $C_6H_5CH(CH_3)OOH$. Oxidation of the ethylbenzene stream in line **1015** can be accomplished by any means know in the art. The temperature and pressure in the EB oxidation zone **1020** is that which is sufficient to substantially oxidize the ethylbenzene in line **1015**. Preferably,

the oxidation occurs at a temperature in the range of about 130 °C to about 160 °C and at a pressure in the range of about 40 psia to about 60 psia.

Step (3) comprises reacting the EBHP stream in line **1025** and a dilute propylene stream in line **1023** in a propylene epoxidation zone to form an impure propylene oxide stream in line **1035** comprising C_3H_60 and methylbenzyl alcohol (MBA), $C_6H_5CH(CH_3)OH$. The reaction that occurs in the propylene epoxidation zone is:

$$C_6H_5CH(CH_3)OOH + C_3H_6 \rightarrow C_3H_6O + C_6H_5CH(CH_3)OH$$

The temperature and pressure in the propylene epoxidation zone **1030** is that which is sufficient to react the EBHP stream with the dilute propylene stream to form an impure propylene oxide stream. Preferably, the reaction occurs at a temperature in a range of about 60 °C to about 120 °C and at a pressure in a range of about 140 psia to about 700 psia. The reaction in the propylene epoxidation zone can be accomplished by any means know in the art. Generally, the reaction of the EBHP stream in line **1025** and the dilute propylene stream in line **1023** is accomplished using a molybdenum catalyst solution.

Step (4) comprises separating the impure propylene oxide stream in line **1035** in a product separator zone **1040** to form a tail gas stream in line **1045**, a residue stream in line **1050**, a raw propylene oxide stream in line **1080**, a MBA/acetophone(ACP) stream in line **1055,** and an ethylbenzene recycle stream in line **1046**. The product separator zone **1040** comprises equipment sufficient to produce the tail gas stream in line **1045**, a residue stream in line **1050**, a raw propylene oxide stream in line **1080**, and a MBA/ACP stream in line **1055.** The ethylbenzene recycle stream in line **1046** is recycled back to be combined with the ethylbenzene stream in line **1015**. Generally, the product separation zone comprises at least one fractionator. The MBA/ACP stream in line **1055**

comprises $C_6H_5CH(CH_3)OH$ and $C_6H_5COCH_3$. The tail gas comprises propylene and propane. The residue stream in line **1050** typically comprises benzoic acid, naphthenic acid, and heavier organic compounds.

Step (5) comprises separating the raw propylene oxide stream in a propylene oxide separations zone **1085** to form a propylene oxide stream in line **1095** and an impurities stream in line **1090.** The separation of the raw propylene oxide in line **1080** to form an impurities stream in **1090** and a propylene oxide stream in **1095** can be accomplished by any means known in the art.

Step (6) comprises reacting the MBA/ACP stream in line **1055** in a styrene production and separation zone **1060** to form a styrene stream in line **1065,** a fuel stream in line **1070,** and a wastewater stream in line **l075**. The reactions that occur in the styrene production and separation zone **1060** comprise the following:

$$C_6H_5COCH_3 + H_2 \rightarrow C_6H_5CHCH_3OH$$

$$C_6H_5CHCH_3OH \rightarrow C_6H_5CH{=}CH_2 + H_2O$$

The styrene production and separation zone **1060** comprises equipment sufficient to produce the styrene stream in line **1065,** the fuel stream in line **1070,** and the wastewater stream in line **1075.**

In another aspect of this invention the acrylic acid is produced. Processes to produce acrylic acid are disclosed in U.S Patents 6,281,384 and 6,069,271; all of which are herein incorporated by reference. An example of this process comprises the following steps as shown in Figure 10.

Step (1) comprises oxidizing a dilute propylene in line **1105** with air in line **1110** in an oxidation reactor zone **1120** to produce a vent gas stream in line **1115** and an aqueous acrylic acid stream in line **1125**. The oxidizing of the dilute propylene comprises the following reactive steps.

(1) $C_3H_6 + O_2 \rightarrow CH_2CHCHO + H_2O$

(2) $CH_2CHCHO + \frac{1}{2} O_2 \rightarrow CH_2CHCOOH$

The oxidation reactor zone comprises equipment sufficient to produce the vent gas stream in line **1115** and the aqueous acrylic acid stream in **1125**. For example, the oxidation reactor zone comprises at least one multi-tubular reactor. For example, reaction step (1) can be accomplished through the use of a multi-tubular reactor using catalysts comprising molybdenum and at least one element selected from the group bismuth, tellurium, and tungsten at a temperature of about 300 °C to about 460 °C. The reactive step (2) can be accomplished by a multi-tubular reactor using catalysts comprising molybdenum and vanadium oxide at a temperature of about 240 °C to about 450 ° C.

Step (2) is separating the aqueous acrylic acid stream in line **1125** in a recovery and purification zone **1130** to produce an acrylic acid stream in line **1135** and a mixed acid/ester waste stream in line **1140**. The mixed acid/ester waste stream in line **1140** comprises water, formic acid, acetic acid, propionic acid, acrylic acid and ethyl acetate. The recovery and purification zone comprises process equipment sufficient to produce the acrylic acid stream in line **1135** and a mixed acid/ester stream in line **1140**. Typically, the recovery and purification zone comprises at least one fractionator.

In another aspect of this invention, the dilute propylene stream is utilized as a feedstock to produce cumene. Processes to produce cumene are disclosed in U.S Patent numbers 5,081,323 and 5,149,894; all of which are herein incorporated by reference. An example of this process involves the following process steps as shown in Figure 11.

Step (1) comprises reacting a dilute propylene stream in line **1200** with a benzene feed stream in line **1205** in a dilute propylene alkylation zone **1210** to produce a raw cumene stream in line **1215**. This step can be accomplished by any means know in the art.

Step (2) is separating the raw cumene steam in line **1215** in a cumene separations zone **1220** to produce a heavies stream in line **1240,** the cumene stream in line **1250,** a dipropylbenzene stream in line **1270,** and a benzene stream in line **1280**. Separating can be accomplished by any means know in the art. A portion of the benzene stream in line **1280** can be recycled and combined with the benzene feed stream in line **1205**.

Step (3) is reacting the benzene stream in line **1280** and the dipropylbenzene stream in line **1270** in a transalkylation reactor zone **1290** to form a transalkylated cumene-rich stream in line **1260.**

Step (4) is separating the transalkylated cumene rich stream in line **1260** in the cumene separations zone **1220** to produce the cumene stream in line **1250**, the heavies stream in line **1240**, the propane stream in line **1230**, the benzene stream in line **1280**, and the dipropyl-benzene stream in line **1270**. A portion of the benzene stream in line **1280** can be recycled and combined in the benzene feed stream in line **1205**.

Optionally, the propane stream in line **1230** can be recycled back to the cracking zone **105** shown in Figure 2.